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Manual Picking from Large Containers – Time Efficiency and Physical Workload

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Abstract: Picking of components from large containers is common both within trade and industry, but is often associated with poor working conditions in terms of ergonomics, as well as with low time efficiency. Providing quantitative evidence from an actual industrial setting, the paper shows how both the picking time and the physical workload varies depending on the position of each component within the container picked from. It is clear that there are considerable differences between the front and the rear sections of the pallet, as well as between the top and the bottom sections. Moreover, the paper shows that picking from a large container that is tilted is significantly better from a perspective of time efficiency. In contrast, the difference in terms of physical workload between picking from a horizontal and a tilted pallet is relatively small for most pallet sections.

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1. INTRODUCTION

Picking operations are increasingly utilised within trade and industry, both in manufacturing industry, where a high degree of product customisation often results in comprehensive materials handling, and in order picking for distribution, following the increase in e-commerce. Most often, the picking operations are performed manually, which sets demands for ergonomically sound, as well as efficient, operations. In this context, the size, configuration, and orientation of the container picked from are essential.

In manual assembly, the configuration of the materials supply system has a considerable effect on the performance of the assembly operations. Previous studies have found that the use of smaller unit loads for supplying and presenting materials to assembly can improve assembly performance in terms of efficiency (Wänström and Medbo 2009, Finnsgård et al. 2011; Hanson 2011), flexibility (Wänström and Medbo 2009), and ergonomics (Neumann and Medbo 2010; Finnsgård et al. 2011). However, in certain situations, large containers, such as EUR-pallets with collars, are still seen as the most feasible and cost efficient means of supplying and presenting materials at assembly stations. This can be the case when the components supplied are too large to fit into smaller containers. Transport efficiency calculations, focussing on space utilisation, can also result in use of large pallets. Even if the use of pallets for presenting parts at the assembly stations is avoided, this is in many cases achieved through some sort of repacking activity in the materials supply system, e.g. kit preparation or repacking to smaller containers. Accordingly, picking from EUR-pallets and other large containers is still common in many assembly environments, either at the assembly stations or in the

materials supply system. Also in order picking, performed in distribution warehouses, picking from large containers, such as EUR-pallets with collars or large cardboard containers, is commonly occurring (De Koster et al. 2007; Dallari et al. 2009). However, picking from large containers is problematic, as it is often associated with poor working conditions in terms of ergonomics, as well as with low time efficiency (Wänström and Medbo 2009). In order to achieve efficiency, as well as ergonomically sound working conditions, it is of interest to study the picking from large containers further.

In manual picking of components from large containers, it seems that both time consumption and physical workload will vary depending on where in the container each component is located, and the location in turn varies as the container is emptied. In the context of repetitive work controlled by a predetermined takt time, which is a context commonly occurring in assembly plants, these variations are likely to result in time losses, as the balancing of the work is made difficult. Moreover, from an ergonomic perspective, it is important to consider the variations in workload, so that not only average load is considered, but also peak load. This is especially important for heavy components, which are often handled in large containers.

Previous studies have highlighted that the design of picking operations can affect both time efficiency (Finnsgård et al. 2011; Finnsgård and Wänström 2013) and physical workload (Neumann and Medbo 2010). In this context, it has been indicated that time efficiency of picking can be improved if the packaging picked from is tilted towards the picker (Finnsgård and Wänström 2013). However, no studies have been found that fully address the variations in time and

workload in the context of picking from large containers. The current paper has the aim of identifying how time and physical workload varies during the picking of components from large containers, depending on the position of each component, and depending on whether or not the container is tilted. Moreover, the paper discusses managerial implications of the findings, making suggestions on how manual picking from large containers could be designed to manage the potential variations, in terms of both time and physical workload.

2. LITERATURE REVIEW

The current section presents a brief review of the existing literature that deals with manual picking of the type focussed on in the paper.

Grosse et al. (2015) present a framework for incorporating human factors into order picking, considering perceptual, mental, psychosocial, and physical aspects. In relation to the physical aspects, Grosse et al. (2015) point out that both the well-being of the picker and the picking time are affected by the location, in terms of depth and height, of the item to be picked. Similarly, Neumann and Medbo (2010) present empirical data according to which the time required to pick a component from the top rear part of a EUR-pallet with four collars is over three times longer than from the lower rear part. Moreover, Neumann and Medbo (2010) compare the picking of components from small containers to that from EUR-pallets with collars and find that picking time as well as physical workload of the operator, in terms of both peak load and cumulative load, is reduced when small containers are used. Similarly, Ciriello (2003, 2007) find that the maximum acceptable weight is dramatically reduced with extended horizontal reach, i.e. with an increased horizontal distance between the picker and the object lifted.

Finnsgrård and Wänström (2013) present a full factorial experiment, studying how picking time is affected by part size, packaging type, and different aspects of how the components are presented. The findings from the experiment include that picking time is on average significantly shorter from a small container than from a pallet with collars, and from a packaging that is tilted (30° angle) towards the picker, compared to one that is almost horizontal (3° angle). Another finding from the experiment is that the sideways position of the parts presentation in relation to the picker affects picking time, so that picking time is shorter for a component straight in front of the picker, compared to one picked at a 30° angle sideways. Kothiyal and Kayis (1995), who studied seated assembly, instead found that parts presentation at a 30° angle sideways from the picker resulted in shorter cycle times than parts presentation straight in front of the picker, which is explained by a more favourable movement of the picker's arm.

Petersen et al. (2005) evaluate slotting measures and storage assignment strategies in the context of order picking. They find that the use of a golden zone, where stock keeping units are stored between the picker's waist and shoulders, can reduce picking time considerably. In this context, Petersen et

al. (2005) take into consideration that picking time is affected by the size and weight of the objects picked.

3. METHODOLOGY

The empirical data were collected at the assembly plant of a manufacturer of heavy duty diesel engines. The study was preceded by interviews and observations which were used by the authors to gain a thorough understanding of the materials handling activities within the plant and to identify suitable activities and components to include in the study. In line with the aim of the paper, both picking time and physical workload were considered in the measurements. The measurements focus on manual picking of components of two different part numbers, one oil filter and one bracket, performed in kit preparation areas that supplied the assembly line with kits. The two studied part numbers differed in terms of component weight, where the filter weighed 1.2 kg and the bracket weighed 5.2 kg. Moreover, the containers holding the two part numbers differed in height, where the filters were held in pallets with three collars and the brackets were held in pallets with two collars. Studying the picking of both of these part numbers could therefore offer insight as to whether component weight or container height affects how time efficiency and physical workload vary depending on the position of each component and depending on whether or not the container is tilted.

In line with the aim of the paper, as presented in Section 1, picking was, for each of the two part numbers, studied both from a horizontally oriented pallet and from a tilted one. Picking from horizontal pallets was the normal way of working at the company, whereas the introduction of tilted pallets was made as part of the research study. The pallets were tilted to 45°, partly because tilting at this angle had been observed during manual picking at other companies, and partly because such a wide angle was believed to result in a significant contrast to the horizontal pallet. During picking, the pallets were placed on racks, elevating them from the floor. The horizontal pallets were placed so that the inside of each pallet bottom was at a height of 50 cm from the floor, and the tilted pallets were placed so that the inside of the bottom corner of each pallet was at a height of 50 cm from the floor. Each pallet was placed so that one of the short ends was facing inwards in the kit preparation area and picking was accordingly performed mainly from this end of the respective pallet. However, when picking from a horizontal pallet, it was not possible for the operator to reach from the short end to the rearmost components in the pallet. Instead, the operator would walk to one of the long end of the pallets to pick these parts. To enable this, a 50 cm wide space had been made available along one of the long ends of each pallet in the kit preparation areas that were studied. With the tilted pallets, the operators could pick all components from the short end of the pallet.

In order to be able to determine how picking time varies within a pallet, each pallet was considered to consist of four sections, as illustrated in Fig. 1. As further illustrated in Fig. 1, each pallet section, for both horizontal and tilted pallet, was given a denotation (H1-H4 and T1-T4, respectively) that

was used further on in the study and in the presentation of the results, as shown in Section 4. The use of four pallet sections was found to constitute a good balance between achieving detailed results and handling the difficulties of manually determining from which pallet section each component was picked: if more sections had been used, the risk of misjudging from which section each component was picked would have increased.

While a division into four pallet sections was used in the measurement of picking time, where a manual judgement was needed to determine from which section each part was picked, a division into six pallet sections was instead used in the calculations of physical workload, as this was found to offer more detailed results than possible with only four sections. These pallet sections, including their denotations used in the study, are also illustrated in Fig. 1.

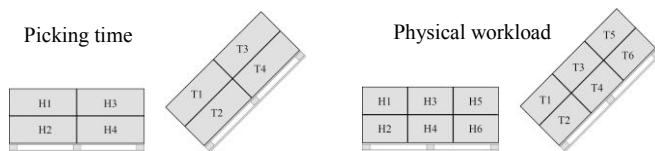


Fig. 1. The sections that each pallet was divided into, both horizontal and tilted, for the measurement of picking time, to the left in the figure, and for physical workload, to the right in the figure. Pallets seen from the side, with front end (facing the operator) to the left.

Picking time was defined as the time for picking one component, from the time the picker pressed a pick-to-light button placed right in front of each pallet, to the time when the component had been removed from the pallet and was no longer directly above it (i.e. when the component had cleared the wooden collar of the side of the pallet that was facing the operator). When picking was performed from the long end of the pallet, the picking time included time for walking from the short end to the long end of the pallet and back.

The measurement was made manually, by two of the authors, using stop watches. Both authors simultaneously studied all picking activities during the emptying of one, initially full, pallet of each of the two part numbers and, independently of each other, noted the measured time for each component picked. Thereafter, the mean of the two measurements for each picking activity was calculated and used for further analysis. Before the data collection, the purpose and methodology of the study were explained to all of the operators involved, so that they would work according to normal standards and at regular pace during the data collection. The same operators were studied picking from both the horizontal and the tilted pallet.

During the data collection, picking time was measured for the components within each pallet section, for both horizontal and tilted pallet. Within the pallets of each of the two part numbers, each section contained the same number of components. For the filters, 20 components were picked from

each pallet section, and for the brackets, 8 components were picked from each pallet section. Accordingly, the number of observations of picking time for each pallet section was 20 for the filters and 8 for the brackets.

The analysis of picking time was, for each of the two part numbers studied, conducted by use of an ANOVA, where the picking time from each of the four different sections of the pallet, as described above and illustrated in Fig. 1, were compared, both for the horizontally oriented pallet and the tilted pallet. This way, it was possible to determine both whether picking time differed between the different section of each pallet, and whether picking time differed between horizontal sections and tilted sections.

The ANOVAs were carried out using SPSS software (www.spss.com). To identify differences between all pallet sections, the Tamhane's T2 post hoc test was used after testing for, and rejecting, variance homogeneity (Levene statistic, $p < 0.05$) for both of the studied part numbers. Note that the ANOVAs are robust to the violation of equal variances in this study since the number of observations was the same for each of the pallet sections for each of the part numbers.

Physical workload was studied by use of the Jack computer manikin (Jack 8.3: www.plm.automation.siemens.com), measuring the low back compression force at the L4/L5 vertebral joint. Simulating the picking of filters and brackets, the computer manikin performed picking both of components weighing 1.2 kg from pallets with three collars and of components weighing 5.2 kg from pallets with two collars. This was done for all six pallet sections, for both horizontal and tilted pallet, as illustrated in Fig. 2 and Fig 3. Using the grasp function of the Jack software, the manikin positioned itself in a posture that enabled picking. The default manikin operator was used in the simulations, corresponding to a male with a height of 174 cm.

4. RESULTS

Results are here presented both for the analyses of time efficiency and for the analyses of physical workload.

4.1 Time Efficiency

The ANOVAs identified significant differences in picking time between the pallets sections both for the filters ($F=67.553$, $p < 0.000$) and for the brackets ($F=72.790$, $p < 0.000$). In Tables 1 and 2, the average picking time per part is presented for each pallet section, both for picking from horizontal and from tilted pallet, together with 95% confidence intervals. Table 1 presents the results for the picking of filters, whereas Table 2 presents the results for the picking of brackets. It is clear that the picking time differs considerably both between different sections within a pallet and between horizontal and tilted pallet. Comparing equivalent sections between horizontal and tilted pallet (i.e. comparing H1 to T1, H2 to T2, etc.), the tilted pallet has significantly shorter picking time ($p < 0.000$) for all these comparisons, for both part numbers.

It is also interesting to consider the differences in picking time between different pallet sections within a horizontal pallet and within a tilted pallet. In particular, the maximum difference observed within each pallet gives an indication of how picking time varies. For the studied components, these differences are presented in Table 3.

Table 1. Filters: the average time for picking each component from each of the pallet sections, both from a horizontal and a tilted pallet. The denotations of the pallet sections match the presentation in Fig. 1.

Pallet section	Average picking time per part (s) $\pm 95\%$ CI	Picking time significantly (all with $p \leq 0.01$) different from that of the following pallet sections
H1	1.66 \pm 0.08	H2, H3, H4, T1, T4
H2	2.41 \pm 0.12	H1, H3, H4, T1, T2, T3
H3	4.06 \pm 0.63	H1, H2, T1, T2, T3, T4
H4	4.60 \pm 0.55	H1, H2, T1, T2, T3, T4
T1	1.35 \pm 0.09	H1, H2, H3, H4, T2, T3, T4
T2	1.69 \pm 0.08	H2, H3, H4, T1, T4
T3	1.74 \pm 0.08	H2, H3, H4, T1, T4
T4	2.13 \pm 0.14	H1, H3, H4, T1, T2, T3

Table 2. Brackets: the average time for picking each component from each of the pallet sections, both from a horizontal and a tilted pallet. The denotations of the pallet sections match the presentation in Fig. 1.

Pallet section	Average picking time per part (s) $\pm 95\%$ CI	Picking time significantly (all with $p \leq 0.05$) different from that of the following pallet sections
H1	2.08 \pm 0.09	H3, H4, T1, T2, T3
H2	2.49 \pm 0.24	H3, H4, T1, T2, T3, T4
H3	3.11 \pm 0.22	H1, H2, T1, T2, T3, T4
H4	3.47 \pm 0.31	H1, H2, T1, T2, T3, T4
T1	1.21 \pm 0.19	H1, H2, H3, H4, T2, T4
T2	1.60 \pm 0.11	H1, H2, H3, H4, T1
T3	1.58 \pm 0.14	H1, H2, H3, H4
T4	1.71 \pm 0.20	H2, H3, H4, T1

Table 3. The maximum difference in picking time observed within each pallet

Pallet sections between which difference was observed	Mean difference (s)	Std. Error (s)	Sig.	Lower bound (s)	Upper bound (s)
Filter: H1-H4	-2.94	0.27	0.000	-3.90	-1.98
Filter: T1-T4	-0.78	0.08	0.000	-1.05	-0.51
Bracket: H1-H4	-1.40	0.15	0.000	-1.94	-0.85
Bracket: T1-T4	-0.50	0.13	0.021	-0.95	-0.04

4.2 Physical workload

Fig. 3 and 4 provide illustrations of the computer manikins used in the analysis of physical workload. The low back

compression force associated with picking from each pallet section, both for horizontal and tilted pallet, are presented in Table 4 for the filters and in Table 5 for the brackets. As seen in tables, the values for all pallet sections, for both part numbers, are well below 3400 N, which is the back compression action limit, set by NIOSH and representing a nominal risk of low back injury for most healthy workers.

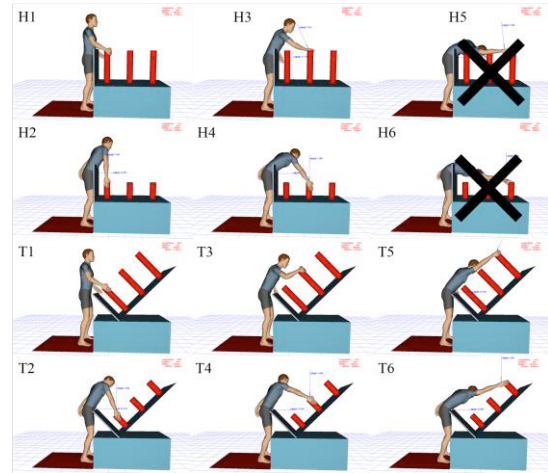


Fig. 2. The computer manikin picking filters in the model.

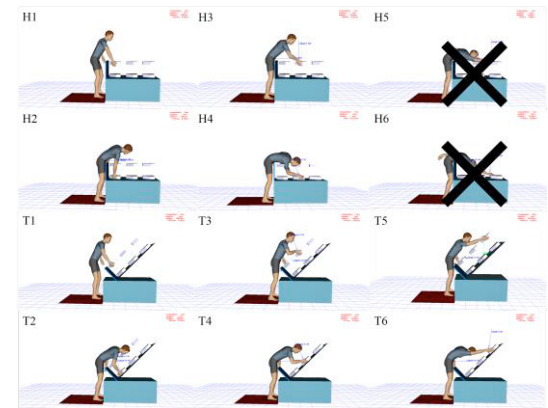


Fig. 3. The computer manikin picking brackets in the model.

As could be expected, the low back compression force is lower for the front and top of the pallet, compared to further back and at the bottom of the pallet. From Tables 4 and 5, it seems that the difference between picking from a horizontal pallet and picking from a tilted pallet is relatively small for most pallet sections. However, picking from the far end of the pallet, as done for the tilted pallet but not for the horizontal one, is associated with a considerably larger force than picking from the front end. As described in Section 3, when picking from the rearmost sections of a horizontal pallet, equivalent to sections H5 and H6, the picker would walk to the long end of the pallet and pick from there, as the components were not possible to reach from the short end. Therefore, as can be seen in Tables 4 and 5, the low back compression force has not been calculated for pallets sections H5 or H6 for either of the two part numbers. Instead, picking from these pallet sections from the long end of the pallet,

the postures of the picker and the low back compression force would be equivalent to picking from pallet sections H1-H4 from the short end of the pallet, because the width of a EUR-pallet (measured from long end to long end) is 80 cm, which is equivalent to 2/3 of the length of the pallet (measured from short end to short end).

Table 4. Filters: the low back compression force for picking from each of the pallet sections in horizontal and tilted pallet. The denotations of the pallet sections match the presentation in Fig. 2.

Pallet section	Low back compression force (N)	Pallet section	Low back compression force (N)
H1	537	T1	523
H2	1473	T2	1669
H3	1372	T3	1332
H4	2027	T4	1717
H5	N/A	T5	1759
H6	N/A	T6	2182

Table 5. Brackets: the low back compression force for picking from each of the pallet sections in horizontal and tilted pallet. The denotations of the pallet sections match the presentation in Fig. 2.

Pallet section	Low back compression force (N)	Pallet section	Low back compression force (N)
H1	1749	T1	1673
H2	2215	T2	2104
H3	2039	T3	1724
H4	2143	T4	2350
H5	N/A	T5	1724
H6	N/A	T6	2658

5. DISCUSSION

Providing quantitative evidence from an actual industrial setting, the paper clearly shows how both the picking time and the physical workload vary depending on the position of each component within the container picked from. It is clear that there are considerable differences between the front and the rear sections of the pallet, as well as between the top and the bottom sections. Moreover, the paper shows that picking from a large container that is tilted is significantly better from a perspective of time efficiency. For the studied part numbers, the measured average time based on the whole pallet differed 45% and 46%, respectively. The maximum differences in picking time between different pallet sections were also considerably smaller for tilted pallets. However, overall the physical workload seems to increase when the pallets are tilted, mainly because all picking is performed from the front end of the pallet, making it necessary for the picker to stretch across the length of the pallet in order to reach the rearmost components. For a horizontal pallet, instead, picking from the front end was not possible for those sections, but was performed from the long end.

Consequently, based on the results of the paper, it seems that the physical workload for picking from tilted pallets will when applied in industry result in similar or increased workload compared with picking from horizontal pallets. It should be noted that the NIOSH limit of 3400 N for low back compression force was not passed for any of the pallet sections, where the maximum observed workload for the bracket, which was the heavier of the two components studied, was 2658 N in the rearmost bottom section of the tilted pallet.

The relations that were identified in the paper are clear for both of the part numbers studied, indicating that they are not depending on component weight or the height of the container picked from. Naturally, however, the risk of physical injury are generally more prominent when heavier objects are picked, which was illustrated by the fact that low back compression forces were higher for the heavier brackets than for the filters.

The results of the paper should be considered within industrial applications, where the benefits of having tilted containers can offer improved performance in terms of time efficiency and thus of cost. However, in order not to create potentially harmful working conditions, it seems that careful analyses should be performed of the physical workload before the tilting of pallets is introduced. In this context, it should be noted that picking from the rearmost sections of the pallet may not always be necessary with tilted pallets, as the components may slide forward in the pallet by force of gravity, if the components in front of them are picked first. The applicability of this approach is dependent on the characteristics of the components: the weight and shape of the components will affect how easy it is to pick a component while others are pressing on it from behind.

Tilting of large containers, such as EUR-pallets, sets demands for the materials handling, potentially in terms of both equipment and process design. A tiltable rack or dolly of some sort is required, and there may be need for adapting the materials supply processes to the picking position, whether it is an order picking station or an assembly station, in case the tiltable rack or dolly sets different demands for replenishment and handling of empty containers. Nevertheless, it seems that the benefits of time efficiency identified in the paper are likely to overshadow potential cost associated with investments in equipment or changes to process design.

As was described in the paper, it was not feasible for an operator to reach the rearmost components from the short end of the horizontal pallet, but these components were instead picked from the long end of the pallet, using the space available along one of the long ends of each pallet. With the tilted pallets instead, where all picking was performed from the short end of the pallets, the pallets could be placed closer together, thus enabling a more space efficient parts presentation. In the studied plant, the space for presenting each pallet was reduced by over 20%. In many contexts, both within trade and industry, space efficient parts presentation is very valuable, both because floor space can be scarce and because walking and travelling distances within the facility are affected by the distances between different part numbers.

There could also be other ways of facilitating picking than tilting the containers. Grosse et al. (2015) recognise the difficulties associated with picking components from the far end of a pallet, and refer to an industrial example where pallets can be rotated to avoid the problem. Considering the results of the current study, and the considerable difference in both time and physical workload between picking from the front or far end of a pallet, this is an interesting approach. However, while addressing the physical workload associated with picking parts from the rearmost sections of the pallet, the rotating of pallets requires time and would result in variations of the picking, which could make the work difficult to balance. Moreover, due to space limitations at work stations, rotating pallets is not feasible in all situations. A rotating pallet would require even more space than the aisle along the long end of the pallet that was used by the company studied in the current paper. As described above, if the pallet is tilted instead, no additional space is required adjacent to the pallet. Other options could be to replace the pallets used with smaller containers to present the parts at the assembly stations, assuming the components can fit into these containers, or to present the parts without containers, in line with the minomi concept (Hanson 2011). Previous studies have identified considerable advantages associated with such approaches (Wänström & Medbo 2009; Finnsgård et al. 2011; Hanson 2011), but such solutions are not always feasible. For example, in order to use minomi to eliminate the need for picking from large containers, the parts would need to be packed without container already at the supplier, in practice making this approach feasible mainly for supply from internal workstations located close by.

In relation to the potential reduction of variation in picking time associated with picking from tilted pallets, and the improved efficiency that this can result in due to improved balancing and reduced slack, it should be acknowledged that a higher intensity of work at a work station may have negative effects on ergonomics. On this topic, Escorpizo and Moore (2007) present an experiment where they find that fast and highly repetitive picking is associated with a detrimental static level of muscle contraction. This relates to the “ergonomics pitfall” discussed by Winkel and Westgaard (1996). However, if picking can be made more efficient, through the use of tilted containers, this does not necessarily result in more repetitive work. Instead, it could be possible to utilise the time savings to let the operator perform other tasks than picking.

In the experience of the authors, the reason within industry for considering tilting pallets for picking is generally a concern for the physical workload of the pickers, rather than time efficiency. Here, the paper provides interesting findings in that it shows that considerable gains can be achieved in time efficiency, as well as in terms of reducing time variation and improving space efficiency. In contrast, the paper does not identify any real benefits in terms of physical workload.

Future research could extend the studies of the current paper. The analyses of physical workload have so far only included a male operator with a height of 174 cm. To expand the generalisability of the study, operators with different

characteristics could be studied. Moreover, manual picking of the type studied in the paper is often performed in a repetitive manner. Measures of cumulative load could therefore be included in future studies.

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